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NEW SOVIET 20-KV CATHODE-RAY OSCILLOSCOPE

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The successful development of cathode-ray oscilloscopes with hot cathodes in the last 10 - 15 years has made possible extensive application of this measuring instrument in various fields of power and radio engineering. The great recording speeds of oscilloscopes with powerful cathode-ray tubes permits the study of processes with a duration of the order of 10^{-8}-10^{-9} seconds.

The equipping of our scientific research and plant laboratories with these instruments is contributing greatly to more rapid solution of many scientific and technical problems.

Cathode-Ray Oscilloscope Circuit

For cathode-ray oscilloscopes intended to record signals of very short duration, the most important elements in a circuit are the switching elements which energize and synchronize different parts of the control circuit. Before designing the circuit, therefore, it is necessary to solve the principal problem -- the type of switching elements which should be used. At present there are two main solutions: (a) the use of spark relays and (b) the use of thyratrons.

The basic characteristics which determine the choice of a switching element are pickup time and stability of operation. By stability we mean that the time of operation remains constant, irrespective of external conditions or, within certain limits, of the amplitude, form, and duration of the control pulses acting on the switching element.

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[The next few paragraphs discuss the relative instability of spark relays, due to changes in atmospheric temperature, pressure, and humidity as well as to overheating and recurrent contamination of the electrodes during operation. Thyratrons are shown to have advantages in their relative stability and trouble-free operation.]

The best available thyratron for the purpose is type TG-2050, filled with inert gas. This thyratron will operate, when the cutoff bias is normal, if a positive pulse with an amplitude of 25-30 v is applied to the grid. As shown by our experiments, pulses with amplitudes of 200-250 v, i.e., a tenfold overvoltage, can be used on the thyratron. This is very favorable for reducing the firing time, which for a TG-2050 thyratron is not over $3 \cdot 10^{-8}$ seconds, and is highly stable, thus permitting a high degree of accuracy in synchronizing the different circuits in the oscilloscope. The accuracy of this synchronization is illustrated by the oscillogram in Figure 1 [see appended figures] in which a single pulse of 0.15 secs duration was taken on the same film. (These and the following oscillograms were taken by the oscilloscope described in this article.)

The circuit controlling the cathode-ray oscilloscope is shown in Figure 2. Its main components are: (1) the pulse-converting circuit, (2) the beam-blocking circuit, (3) the time-base circuit, (4) the power supply for the cathode-ray tube, and (5) the calibration circuit.

The pulse-converting circuit is switched in the control circuit so that the oscilloscope may be started by an external pulse of any polarity.

The order of circuit operations is as follows: The external pulse acts on the pulse-converting circuit, which actuates the beam-blocking circuit and the time-base circuit simultaneously. When these circuits are in operation, a cathode ray appears, and its deflection in the time direction starts simultaneously.

Converter Circuit for External Pulses

To secure definite synchronization of the beam-blocking and time-base circuits, the converter circuit must generate a pulse with a very steep front and a definite duration which is independent of the form and duration of the external pulse.

When a positive pulse is supplied by an external source, it serves to cut off thyraton L_1 still further and causes thyratron L_2 to conduct. The capacitor C_{12} discharges through the resistor R_{29} and a positive pulse with a steep front is fed through capacitors C_{14} and C_{40} into the circuit.

When a negative pulse is delivered, thyratron L_1 begins to conduct, because its cathode potential becomes negative with respect to the grid potential. Capacitor C_{11} discharges through resistor R_{30} and a positive pulse is delivered to the grid of thyratron L_2, allowing it to conduct. Thereafter, the process continues as described above.

To make it possible to record periodic oscillations and zero lines, push button K was provided for starting the oscilloscope. When push button K is depressed, capacitor C_8 discharges through the winding of relay RP, closing its contact. Capacitor C_{10} is charged through the relay contacts and resistor R_{26} from capacitor C_9 up to a positive potential which causes thyratron L_1 to conduct, and the circuit operates in the same manner as when a negative pulse is fed in.

Beam-Blocking Circuit

To prevent burning the screen and exposing the photosensitive emulsion to light before the beginning and after the end of recording, the beam must appear on the screen only while the oscillogram is being recorded. The beam is cut off in a cathode-ray tube by means of a negative bias (with respect to the cathode) applied to the tube modulator. To initiate a beam, a positive pulse of a definite form and duration must be fed into the modulator. The beam-blocking circuit also functions to generate such pulses.

The pulse which initiates the beam should be as close to a square wave as possible to ensure constant clarity of the record over the entire screen. Another important requirement is simplicity and accuracy of control over the duration of the initiating pulse. The quality of the oscillogram depends largely on accuracy in controlling the pulse duration. In the course of designing the cathode-ray oscilloscope circuit, we tried many types of beam-blocking circuits. However, they did not satisfy either of the above requirements. Therefore, we developed in the laboratory the unique beam-blocking circuit shown in Figure 2, which gave satisfactory results.

The synchronizing pulse is fed through dividing condenser C_{40} to the grid of thyraton L_6 and fires it. When the thyratron conducts, capacitor C_{41} begins to discharge through resistor R_{55}; a very steep-fronted positive pulse, initiating the beam, is fed into the modulator through the small resistor R_{51} and the dividing condenser C_{37}. The time constant of the front, determined as the product $C_{ak} R_{51}$, will be considerably less than the firing time of the thyratron ($C_{ak} = 4\ \mu\mu fd$). The pulse-amplitude decay is determined principally by the values of resistor R_{55} and capacitor C_{41}. The magnitude of R_{55} is selected so as to maintain, within the limits of the full sweep, an approximately constant pulse amplitude. Moreover, resistor R_{55} must ensure the flow through thyratron L_6 of a current sufficient to sustain a stable discharge in it. The function of thyratron L_5 is to block the beam. Until the circuit has operated, this thyratron is cut off by the negative bias fed to the grid through the high resistance R_{52}. The bias is kept sufficiently stable by means of the small capacitor C_{39}.

When thyratron L_6 fires, the capacitor C_{39} begins to charge through resistance R_{53} and the dividing condenser C_{38}. When the capacitor C_{39} is charged to the voltage value which allows thyratron L_5 to conduct, the pulse is cut off in the modulator and the beam is blocked. Resistor R_{51} serves to limit the current across the thyratron when the wave is cut off. Varying the magnitude of the resistor R_{54} makes it possible to control the cutoff time of the pulse fed to the modulator over a wide range. Resistor R_{53} determines the minimum length of the pulse when R_{54} is at a minimum. The operation of the circuit is illustrated by the oscillograms in Figure 3, a, b, and c, which show pulses of various durations.

The Time-Base Circuit

The circuit which produces the time displacement is one of the most important components of the control circuit of a cathode-ray oscilloscope. In selecting this circuit, the following conditions were imposed: (1) uniformity of beam motion on the screen (linear sweep); (2) symmetry of sweep-voltage variations to avoid distortion of the picture and defocusing of the beam; (3) limits for regulating the sweep duration of 0.1 to 100 μsec or more; (4) all tubes used in the circuit must be Soviet-produced.

Under these conditions the circuit selected gave complete satisfaction.

The principle of the operation of this circuit is graphically illustrated by the schematic diagram in Figure 4, in which the beam tetrode L_4 is replaced by the switch K and the variable resistance R. The capacitor C_1, dividing capacitors C_2, and the deflecting-plate capacitance Cdp are charged from the voltage divider through resistor R_3. The positions of the sliding contacts in the divider are selected in such a manner that the plate potentials will be equal to $+U/2$ on the right and $-U/2$ on the left, that is, symmetrically with respect to the last plate of the cathode-ray tube (ground). With such potentials, the beam is deflected to the edge of the screen. The total voltage applied to capacitor C_1 equals 2U.

Resistors R_2 and R_3 are sufficiently large to isolate the rapid sweep process from the voltage divider and the other components of the circuit. Capacitors C_2 are large enough so that their charge cannot vary by any appreciable amount during the sweep.

When switch K is closed, capacitor C_1 discharges through the nonlinear resistor R_1, thus ensuring the linearity of the sweep. During discharge, the potentials of the capacitor plates approach their mean value (zero) with a definite speed, which depends on the capacitance value. The plate potentials of capacitors C_2 follow these changes, and since their charge does not vary during the sweep, the potentials of the time-base plates also follow these variations. As a result, the plate potentials change their signs, that is, the voltage is reversed, causing a deflection of the beam to the opposite edge of the screen.

In the actual circuit (see Figure 2), the components K and R are replaced by the tube L_4, which ensures a practically linear variation in voltage when the capacitor C_1 discharges. To keep the discharge from the sweep capacitor constant, the voltage applied to the control grid of tube L_4, causing it to conduct, must remain constant with respect to the varying potential of its cathode during the sweep. Therefore, thyratron L_3 is included in the circuit. Through this thyratron (during firing), a positive potential is applied to the control grid of L_4 from the large capacitor C_{23}, one of whose plates is connected to the cathode.

The circuit is activated by feeding a synchronizing pulse to the control grid of the thyratron. The choice of the type of pentode or beam tetrode installed is extremely important, since the tube must keep the discharge current constant to obtain an even sweep, and this current (saturation current) must be sufficient to provide rapid sweeps. Many tubes were tested in the laboratory, and operating conditions were selected for each tube to produce the highest possible saturation current of sufficient constancy.

The oscillogram (see Figure 5) shows graphically the operation of several tubes for the sweep circuit (recording sinusoidal oscillations with a period $T = 0.3$ μsecs for various tubes in the circuit and for the same capacitance value of the circuit). A 6P3 beam tetrode, which is quite sensitive to small changes in capacitance, was chosen for the circuit. This tube was selected because of its widespread use and ease of replacement.

To calculate the values of the capacitors C_{24} - C_{31} used for varying the degree of sweep, it was necessary to know the value of the saturation current of tube 6P3. For this purpose, an oscillogram of voltage during operation (see Figure 6) was taken. This oscillogram also illustrates the linearity of the sweep.

At a given saturation current (the discharge current of capacitors C_{24} -- $-C_{31}$), the value of the capacitance for a given length of sweep t is determined as $C = \frac{i_s t}{U}$, where i_s is the saturation current; t is the duration of the sweep; and U is the voltage up to which the capacitance must be charged before discharging (determined by the sweep plate sensitivity and screen diameter).

The oscillogram was made at two values, i.e., $C = 0.1$ μfd and $C = 0.05$ μfd. It follows from this oscillogram that $i_s = \frac{CU}{t} = \frac{0.1 \cdot 500}{30} = \frac{0.05 \cdot 1{,}000}{30}$ 1.66 a

Taking the voltage $U = 3$ kv, which corresponds to sweep of a 120-mm screen (the useful part of a screen with a diameter of 130 mm), we obtain the values (in the table below) for the capacitance C for different sweep durations.

t in μsec	1,000	100	10	1	0.1
C in μ fd	0.55	0.055	0.0055	$55 \cdot 10^{-5}$	$55 \cdot 10^{-6}$

The correctness of this method of calculating sweep stages is confirmed by the oscillogram in Figure 7 recording sinusoidal oscillations with a period $T = 7.8$ μsec when the values of the main sweep capacitance is 0.1, 0.05 and 0.035 μfd. The length of the oscillogram on the screen was 40 mm. The time of the oscillogram when $C = 0.1$ μfd was 60 μsec, when $C = 0.05$, 30 μsec, when $C = 0.03$, 20 μsec corresponding to a 120-mm sweep in 180, 120 /sic/ and 60 μsec.

For the given capacitance values, calculations give the same sweep durations. As is clear from the table, for a sweep duration of 0.1 μsec the value of the main capacitance must equal 55 $\mu\mu$fd. It is evident that it is unnessary to include an additional capacitor to obtain this capacitance, since the internal capacitance of the circuit is usually of this order.

The capacitance Cpc /plate-to-cathode capacitance/ of a 6P3 equals 8.5 $\mu\mu$fd. Consequently, to obtain a sweep of 0.1 μsec, wiring capacitance of the circuit must be 46.5 $\mu\mu$fd. Since the circuit wiring is quite complicated, a capacitance of less than 70-80 $\mu\mu$fd usually can not be successfully obtained, and for higher-speed sweeps more powerful tubes (pentode oscillators) are employed.

In this oscilloscope, an especially successful arrangement of the parts made it possible to lower the wiring capacitance to 24.5 $\mu\mu$fd, obtaining thereby a sweep of 0.06 μsec for the whole screen. With this duration, phenomena lasting 0.01 μsec over a 20-mm sweep can be examined in detail.

Power Supply for the Cathode-Ray Tube

The circuit includes a voltage divider and a rectifier with a high-voltage transformer. The electrodes of the cathode-ray tube are connected with an ohmic voltage divider having a total resistance of the order of 20 MΩ (1 MΩ per kv voltage drop across the divider). The capacitors C_2--C_7 are connected between the various components of the divider, thus causing the electrode potentials of the tube to remain more stable.

A special small transformer with a maximum voltage of 30 kv was designed to feed the tubes. This transformer voltage was selected to allow for the voltage drop in the rectifier and the possibility of boosting the voltage applied to the cathode-ray tube. The oscilloscope is supplied from a 220-v line. Interlocking was provided so that the voltage can be applied to the power transformers only after the filament transformers have been switched on.

The oscilloscope has a calibration circuit which can generate sinusoidal oscillations with a period of 0.1 to 50 μsec.

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Construction of the Cathode-Ray Oscilloscope

(The cathode-ray tube was designed and built at the All Union Electrical Engineering Institute (VEI) by Senior Scientific Associate G. M. Topchiyev.) An external view of the oscilloscope is shown in Figure 8. The screen of the horizontally-mounted cathode-ray tube is located at the upper central part of the cabinet. The screen diameter is 130 mm. Knobs for beam control are placed on the left and right of the front panel. Somewhat lower, sliding support is provided for attaching a camera Furthermore, a special device is provided for photographic recording. Attached to the cathode-ray tube screen, it is shaped like a tube, is fitted with a camera for film 6 cm in width, and has an f12 lens built in.

Mounted on the lower, inclined panel are the switches for the filament and power transformers, the rheostat for voltage regulation, and the other controls.

The oscilloscope is mounted on a base of steel tubing.

Each of the circuits discussed above is mounted as a separate unit in the oscilloscope cabinet and can be easily removed to facilitate assembly and replacement of parts This arrangement also ensures dependable shielding of the circuits. The units are so arranged with respect to one another that the circuits can be connected with short wires wherever necessary, for example, between the sweep circuit and the time-deflection plates, between the beam-blocking circuit and the tube modulator, or between the circuit to be studied and the signal plates of the cathode-ray tube.

Recording Speed of the Cathode-Ray Oscilloscope

Maximum recording speed is extremely important, since it determines the field of the oscilloscope's application. By maximum speed we mean the highest velocity of motion of the beam for which a photosensitive emulsion will hold an impression sufficiently dark to be usable after development The amount of darkening in the film is determined by means of a microphotometer. The minimum admissable degree of darkening is assumed to be equal to 0.1.

The maximum speed can be determined by taking an oscillograph of sinusoidal oscillations with a known frequency according to the formula $v = A2\pi f$, where A is the amplitude and f is the frequency of the oscillations.

[The intervening paragraphs discuss the disadvantages of determining maximum recording speed through use of an oscillogram of oscillations in a line which is connected directly to the plates of the cathode-ray oscilloscope.]

Taking an oscillogram of the sinusoidal oscillations of a vacuum-tube oscillator is a simple and reliable method of determining the maximum recording speed. In this case it is easy to determine the oscillation frequency by means of a wavemeter. We selected a vacuum-tube oscillator with a frequency of up to 100 Mc to determine the maximum recording speed of the cathode-ray oscilloscope. The frequency was determined by means of a [illegible]-3 wavemeter.

The oscillogram in Figure [illegible] records oscillations with a frequency of $f = 50$ Mc ($T =$ [illegible] μsec), amplitude A = 2 cm (the oscillogram in Figure [illegible] and 10 are on a smaller scale). The recording speed, determined according to this oscillograph is:

$$v = 2\pi \cdot [illegible] \cdot 10^{6} \cdot 2 \cdot 10^{-5} = [illegible],2[illegible] \text{ km/sec}$$

The curves were plotted on a 1:1 scale with the aid of an f/2 lens on a film with a sensitivity of [illegible] H and D [Hurter and Driffield].

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As we know, to compare the recording speeds of different oscillographs, the recording speed must be corrected for an f/2 lens. This corrected speed is determined by the formula

$$v_{cor} = \frac{v}{(1:F)^2}$$

or $v_{cor} = 6.280 \cdot 4 = 25{,}120$ km/sec.

This oscillogram illustrates the power of the time-base circuit. One oscillation period $T = 0.02$ μsec takes up a 40-mm section of the screen. Thus, for the whole screen (120 mm) the sweep is equal to 0.06 μ sec.

The oscillogram in Figure 10 shows sinusoidal oscillations with a frequency $f = 100$ Mc ($T = 0.01$) and an amplitude $A = 2.5$ cm. The recording speed, determined according to this oscillogram, amounts to:

$$v = 2\pi \cdot 100 \cdot 10^6 \cdot 2.5 \cdot 10^{-5} = 15{,}700 \text{ km/sec.}$$

Correction for the normal f/1 lens gives:

$$v_{cor} = 63{,}000 \text{ km/sec}$$

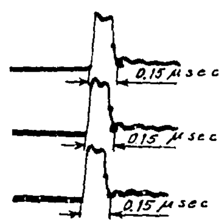

Figure 1

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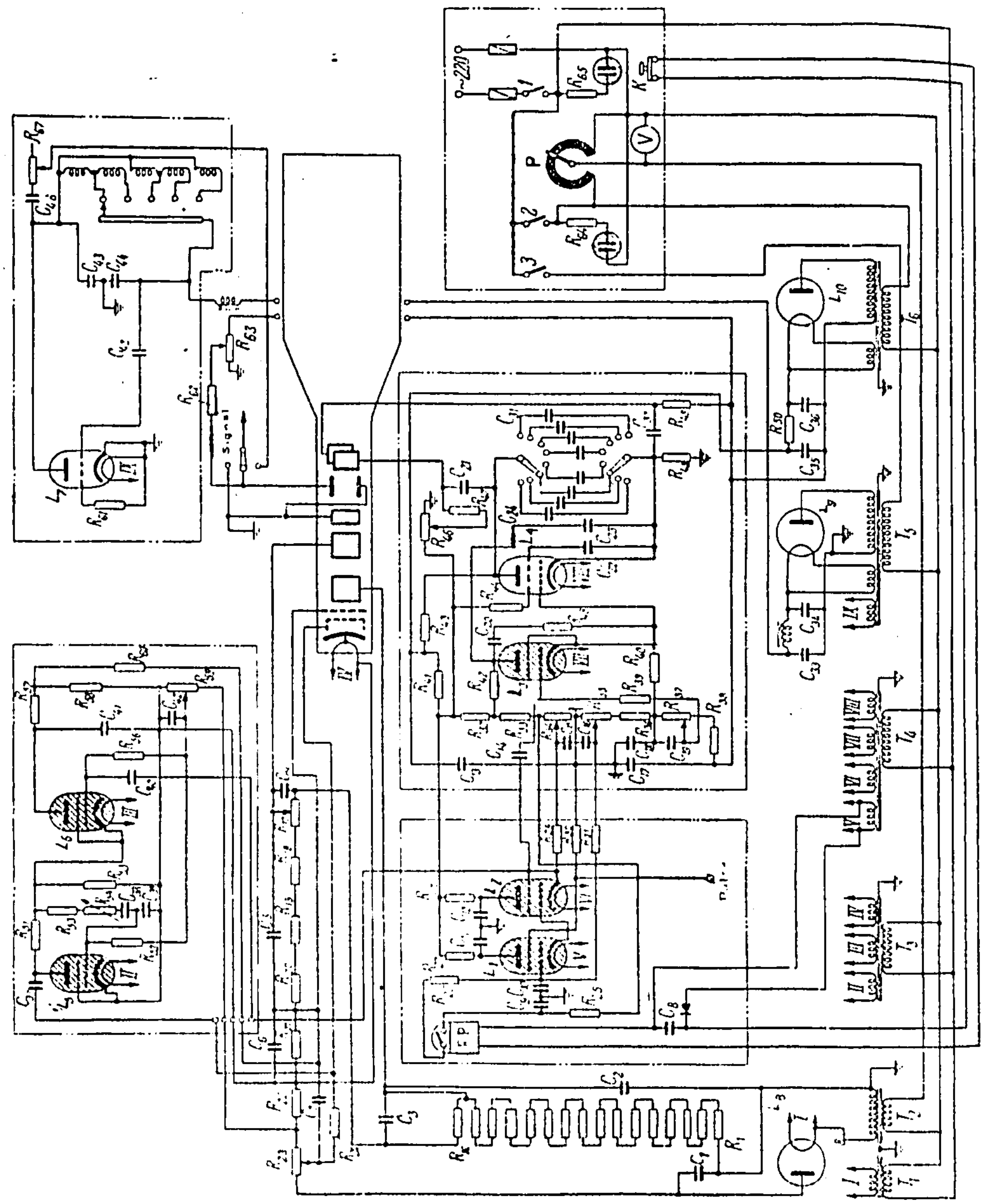

Figure 2. Beam-Blocking Circuit for C-R Oscilloscope

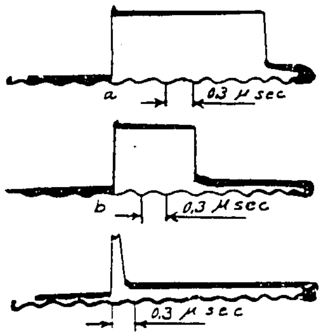

Figure 3

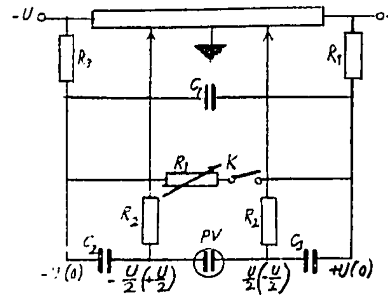

Figure 4

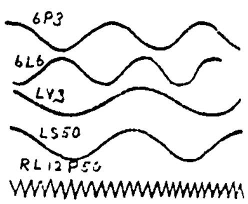

Figure 5

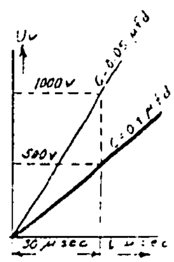

Figure 6

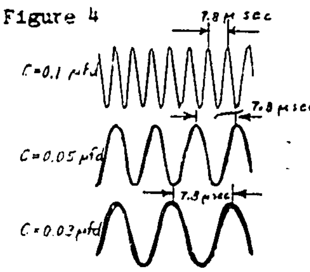

Figure 7

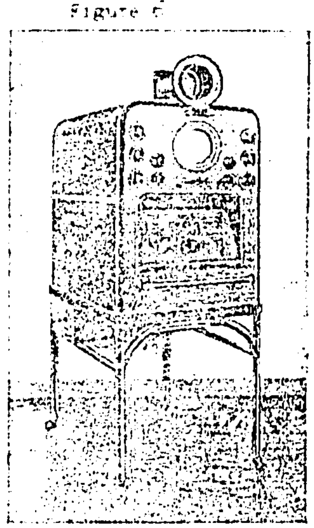

Figure 8

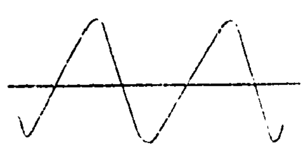

Figure 9

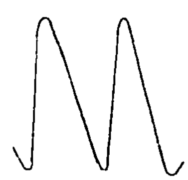

Figure 10

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